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1/77

20AUG03 E831591-1 C84969
P01/7700 0.00-0319518.7

Request for grant of a patent

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19 AUG 2003

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1.	Your reference	E1043.GB#
2.	Patent application number *(The Patent Office will fill this part in)*	0319518.7
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Plextek Limited London Road Great Chesterford Essex CB10 1NY United Kingdom
	Patents ADP number *(if you know it)*	08696205001
	If the applicant is a corporate body, give the country/state of its incorporation	(Incorporated in the UK)
4.	Title of the invention	Location Monitoring Apparatus
5.	Name of your agent *(if you have one)*	
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Electronic Intellectual Property Suite 308, The Foundry 156 Blackfriars Road London SE1 8EN
	Patents ADP number *(if you know it)*	08144297002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

Number of earlier UK application	Date of filing *(day / month / year)*

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request? — Yes

Answer YES if:

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.

Otherwise answer NO (See note d)

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form

Description 16

Claim(s) 7

Abstract 1

Drawing(s) 7 + 7

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10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for a preliminary examination and search (Patents Form 9/77)

Request for a substantive examination (Patents Form 10/77)

Any other documents (please specify)

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11. I/We request the grant of a patent on the basis of this application.

Signature(s) Date

~~18 August 2003~~

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12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom

Mr Jerome Spaargaren – 020 7721 7152

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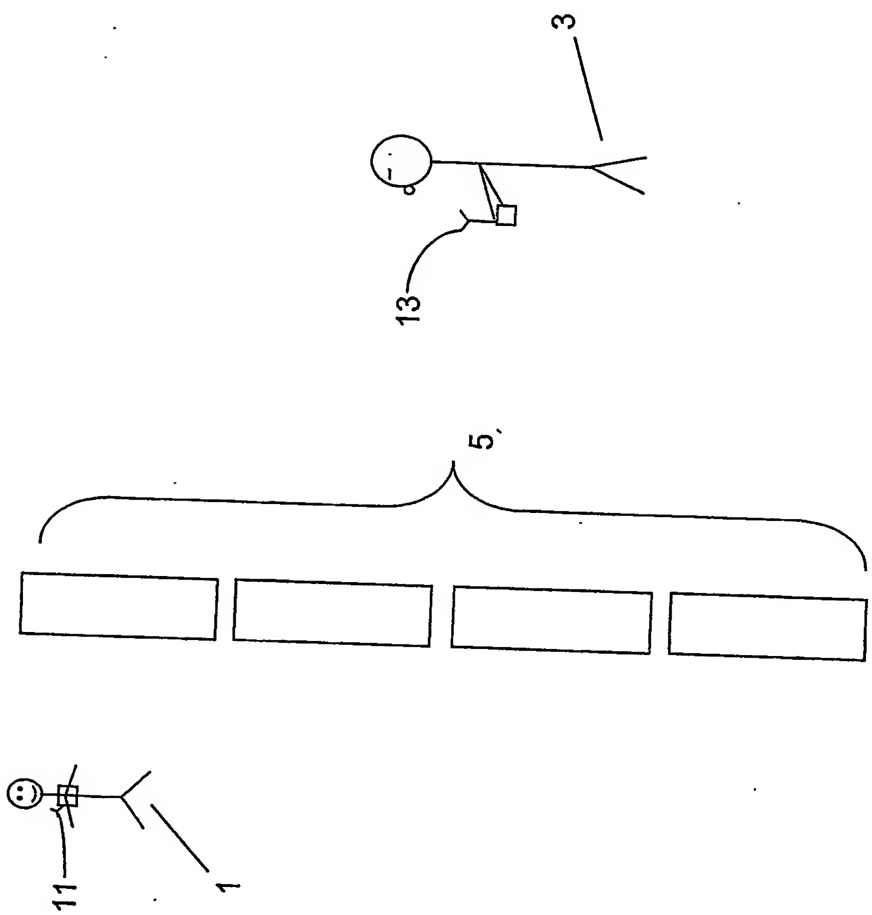
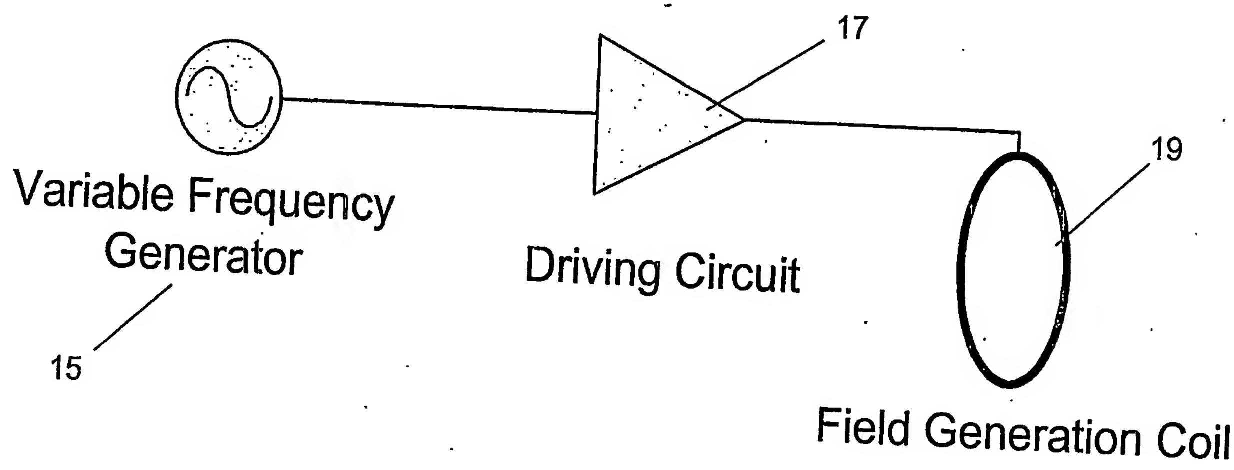


FIG. 1



17
19
Variable Frequency Generator
15
Driving Circuit
Field Generation Coil

FIG. 2

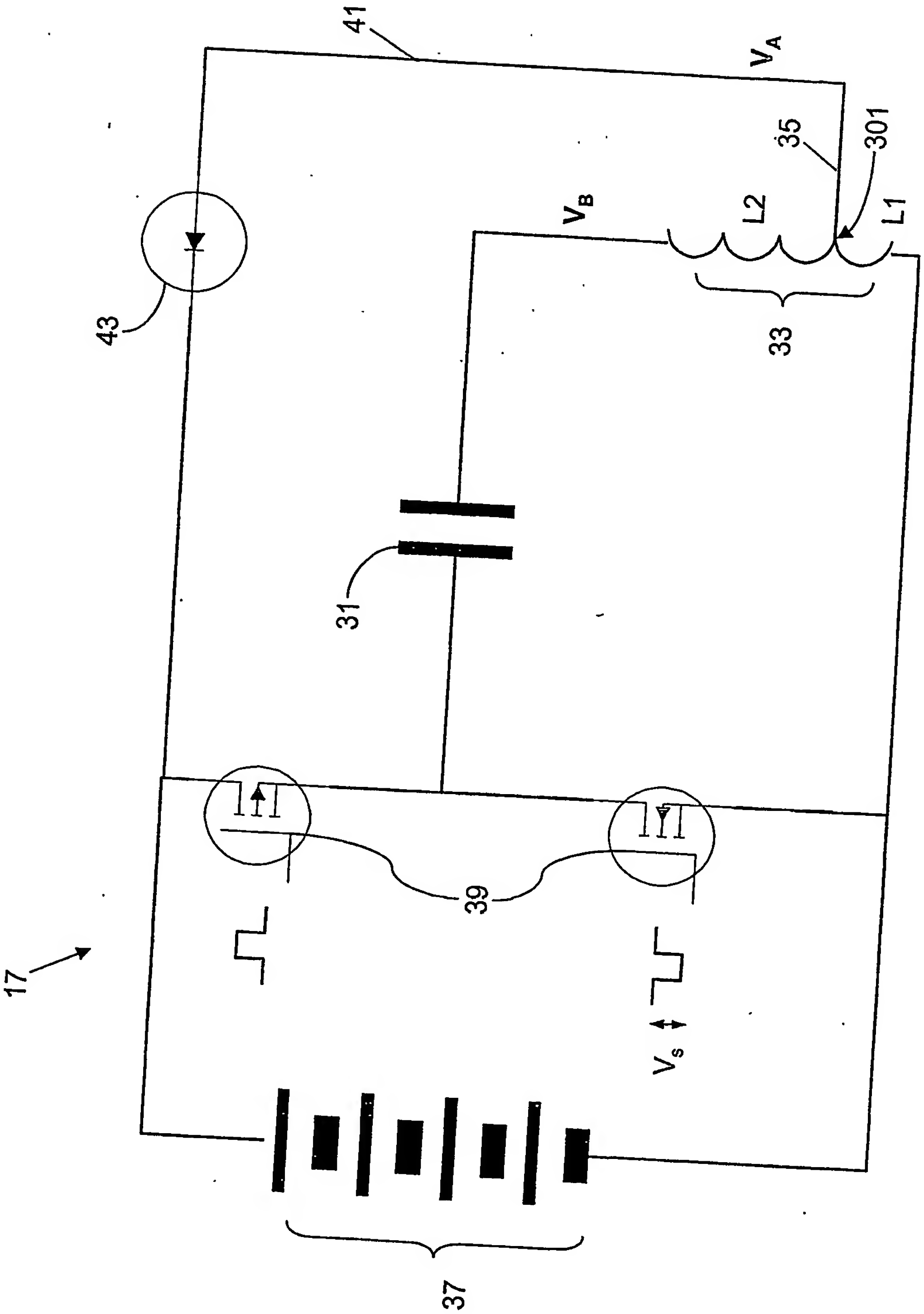


FIG. 3

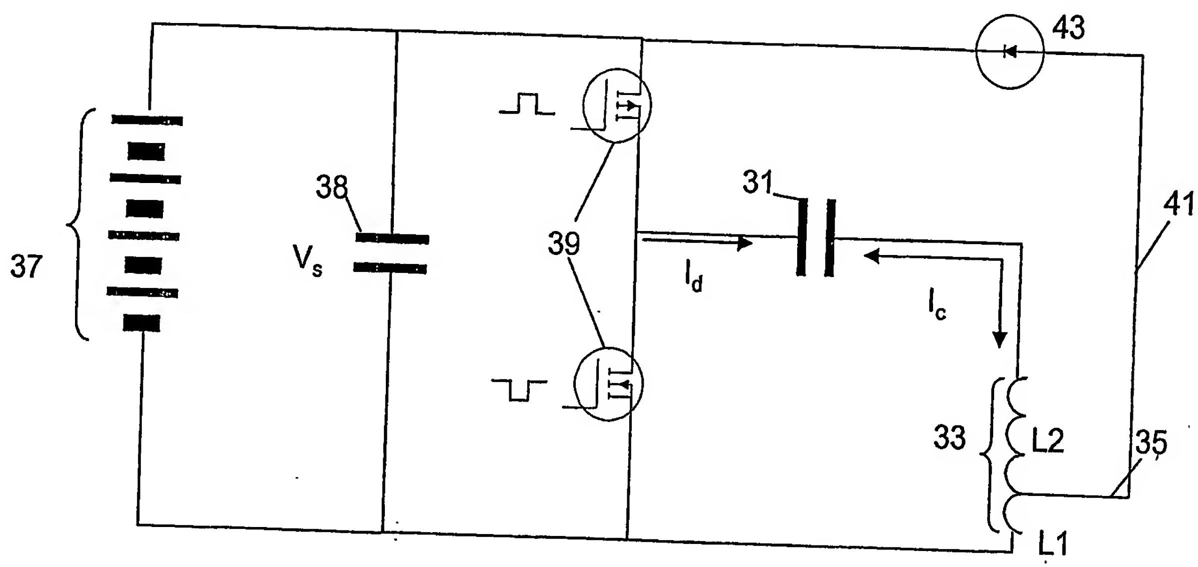


FIG. 4

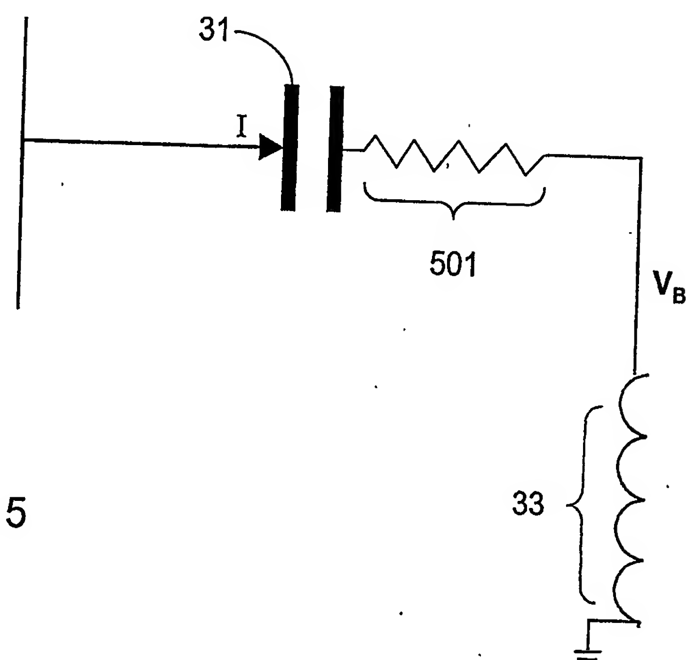


FIG. 5

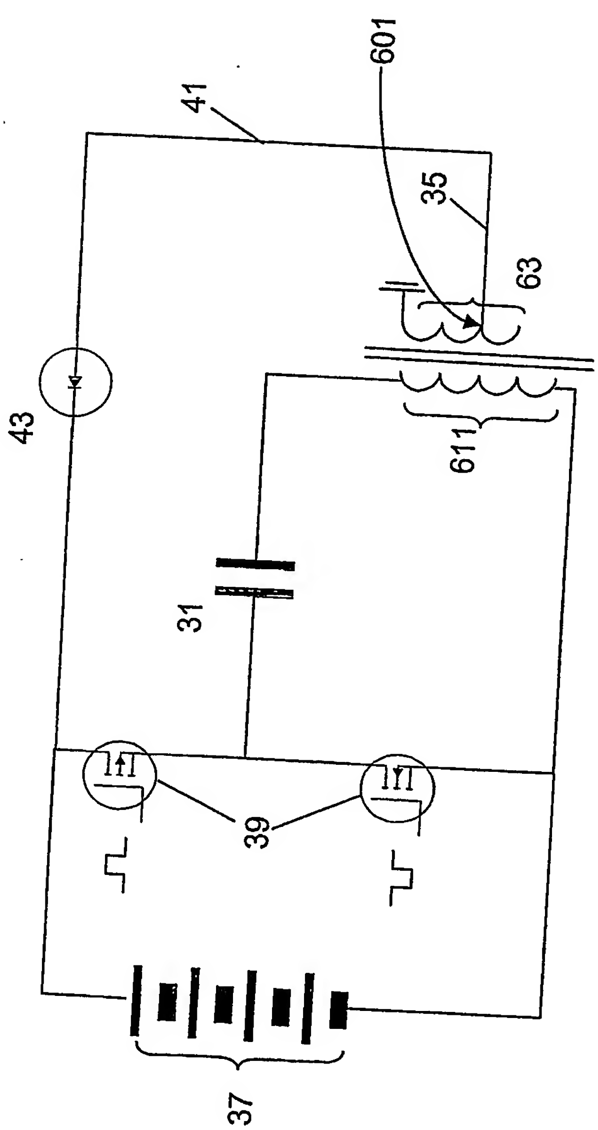


FIG. 6

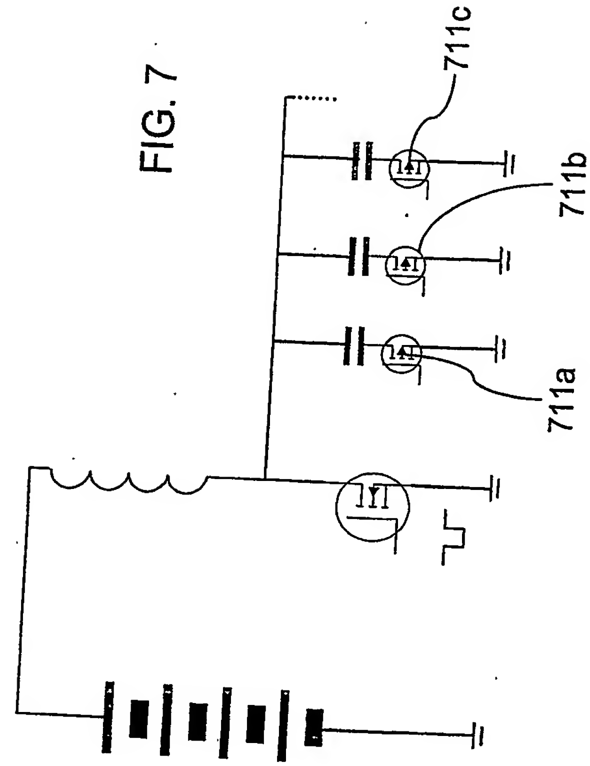


FIG. 7

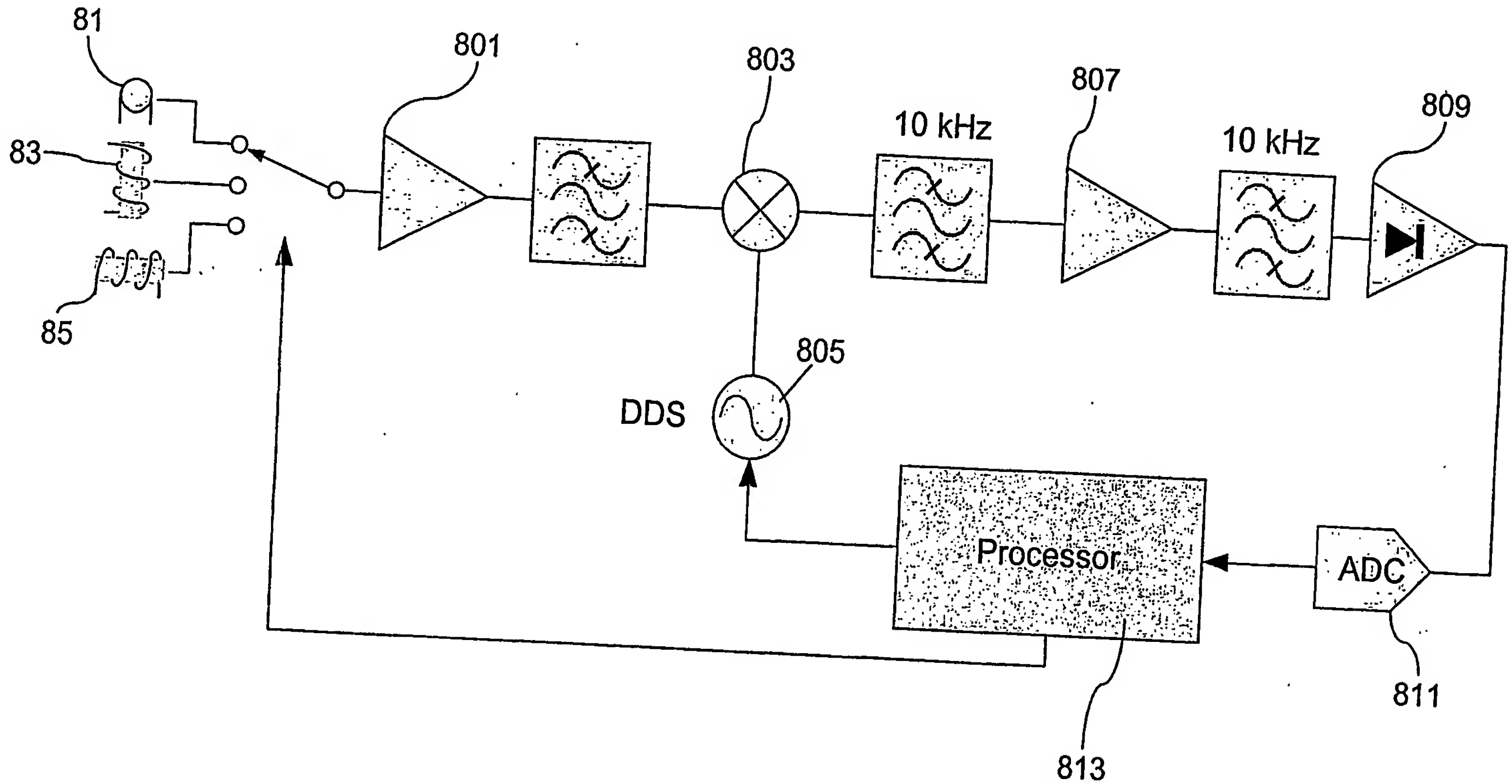
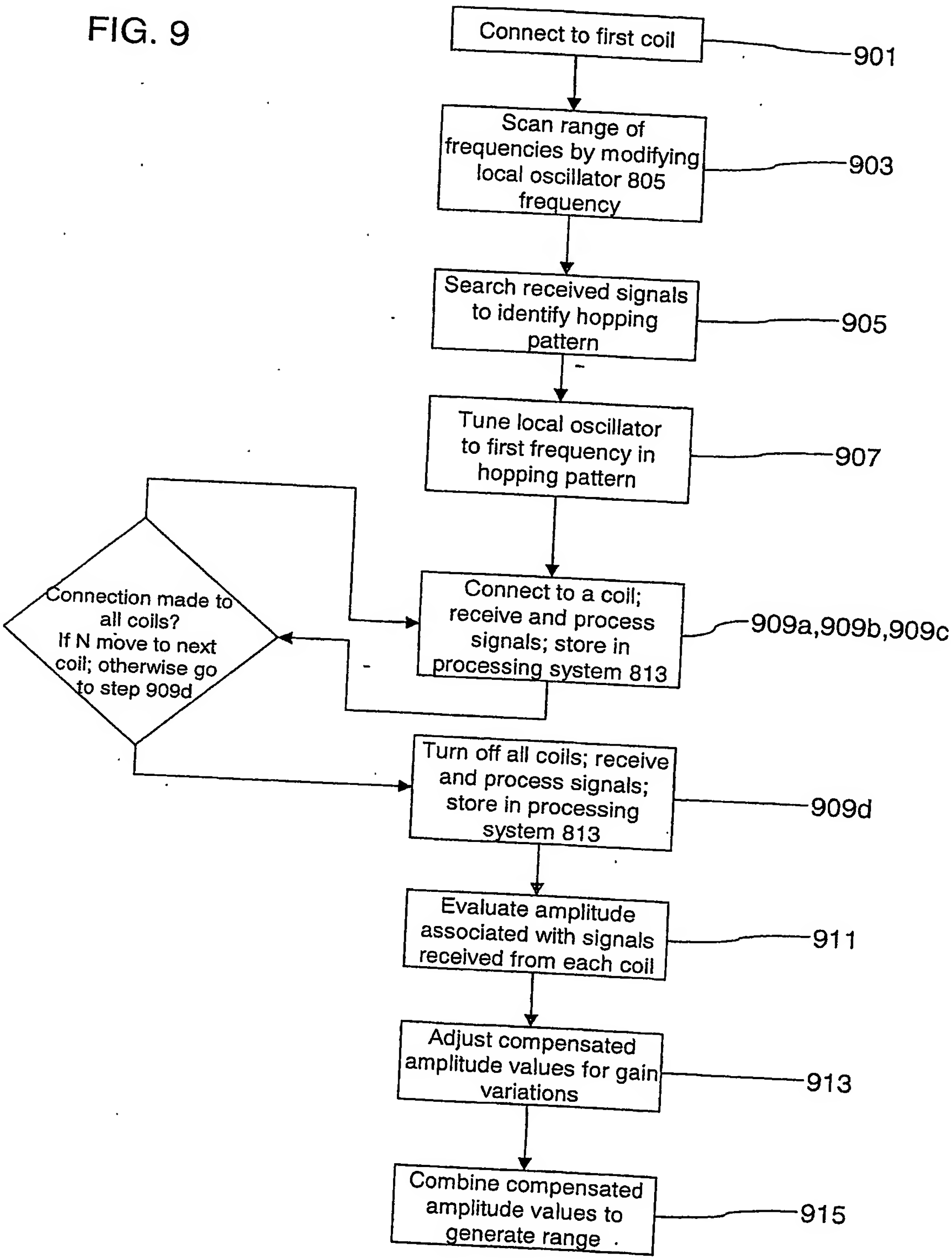

81
83
85
801
803
10 kHz
807
10 kHz
809
805
DDS
Processor
ADC
811
813

FIG. 8

FIG. 9


Connect to first coil
901
Scan range of frequencies by modifying local oscillator 805 frequency
903
Search received signals to identify hopping pattern
905
Tune local oscillator to first frequency in hopping pattern
907
Connect to a coil; receive and process signals; store in processing system 813
909a,909b,909c
Connection made to all coils? If N move to next coil; otherwise go to step 909d
Turn off all coils; receive and process signals; store in processing system 813
909d
Evaluate amplitude associated with signals received from each coil
911
Adjust compensated amplitude values for gain variations
913
Combine compensated amplitude values to generate range
915

DUPLICATE

Location monitoring apparatus

Field of the Invention

The present invention relates to location monitoring apparatus and is concerned particularly with radio frequency location monitoring apparatus that operate in the low radio frequency range. The present invention also relates to radio frequency transmitter and radio frequency receiver designs generally.

Background of the Invention

Identifying the relative or absolute location of an object has always been of interest, and historically it has been an almost essential part of survival. As a result, development of technical means for identifying location has always had momentum. More recently location based services (which deliver content based on a location) have become increasingly popular, so that location is now used in leisure applications as well as the traditional applications of security and survival.

There is a myriad of methods for identifying the location of an object and corresponding means for performing those methods, and these can be broadly categorised according to range (distance to the object that you are trying to locate); whether or not bearing is required (actual location of the object relative to your location or relative to magnetic north); and accuracy required. In general, location monitoring systems are adapted to identify the location of objects located some distance away (in the context of security and survival, one would want to locate an enemy when the enemy is far away, rather than when he is close), which means that high frequency signals, which can propagate over significant distances, are preferably used. For example, mobile communication (including location finding) operates in the Ultra High Frequency (UHF) range; GPS (global positioning satellite) is a form of satellite communication, which operates in the Super High Frequency band (3 – 30 GHz). Although high frequency signals facilitate excellent temporal resolution of signals, they are subject to reflection from objects having a characteristic length greater than their

wavelength, and to absorption by human bodies and trees and the like. In addition, received signals can destructively interfere at the receiver, causing a problem known as fading. As a result a transmitted signal can arrive at the receiver having been reflected off one or more objects (this is known as multi-path propagation), or not at all. Thus the indicated direction can be completely erroneous or non existent.

Whilst these problems can be reduced by employing several or more receivers, this increases the complexity and cost. Essentially, therefore, in order to provide accurate measurements of location at reasonable cost, high frequency systems require a clear line-of-sight between the antennas of the transmitter and receiver, which is difficult to achieve for most ground-based location determining systems.

In addition to the GPS method mentioned above, examples of known location monitoring methods include "angle of arrival", "time of arrival", and "received signal strength indicator" (RSSI). With the "angle of arrival" method, a receiver scans an area in order to identify location, in terms of an angle relative to the receiver, of a signal emitted by a transmitter. Angle of arrival methods typically utilize high frequencies, so as to avoid interference problems associated with low frequency signals, and thus suffer from the multi-path and obstruction problems described above; such a method is described in international patent application PCT/GB90/00077, publication number WO90/08060. The second method, "time of arrival", involves two or more receivers evaluating the time of arrival of a pulse emanating from a transmitter, from which the distance of the transmitter, relative to the two receivers, can be identified. In order to measure time accurately, the resolution of the pulse has to be fine, which means that such systems use high frequencies, and are subject to the reflection and absorption problems described above, so that the time of arrival can be the "time of arrival after experiencing several reflections" and thus highly inaccurate. The third method, "received signal strength indicator" (RSSI), evaluates the strength of the signal received, and, applying Maxwell's equation relating signal strength to distance, evaluates a distance relating thereto. Since this method is wholly dependent on signal strength, it is

particularly sensitive to fading, where the signals received destructively interfere with one another, yielding no signal strength whatsoever. Applications utilizing RSSI to identify location are described in United States patent US 5,714,932 and United States patent US 5,218,344.

An object of the present invention is to provide an improved location monitoring system.

A further object of the invention is to provide improvements to transmitter and receiver designs generally.

Summary of the Invention

According to an aspect of the present invention there is provided location monitoring apparatus, comprising a variable frequency transmitter operable to selectively transmit signals at a plurality of different frequencies, each of which is less than 1 MHz.

An advantage of having a variable frequency transmitter is that ambient noise can be filtered out, since noise is typically constant over time and concentrated at particular frequencies. An advantage of operating in the low frequency range is that multi-path problems associated with high frequency equipment, such as reflections from objects located between the path of the transmitter and receiver, are significantly reduced. In addition, due to the fact that low frequency devices operate in the near field, where that signal strength is proportional to the inverse cube of distance from the transmitter, location can be identified extremely accurately. In some circumstances, this distance can be identified to within ±10 mm.

In one embodiment the location monitoring apparatus comprises an antenna circuit having a variable impedance and a frequency bandwidth associated therewith, the frequency bandwidth defining a frequency band within which the radio frequency transmitter is operable to transmit signals. The antenna circuit is operable to modify the impedance so as to modify said frequency bandwidth, and to transmit a radio frequency signal having a frequency within said modified frequency bandwidth.

Preferably the antenna circuit comprises a coil having a plurality of

windings and tapping means for connection to said windings. The tapping means is arranged to vary the loss associated with the antenna circuit by connection to a set of the plurality of windings, thereby removing energy from the coil and reducing the Q factor of the coil. By reducing the Q factor of the antenna circuit the bandwidth thereof is increased, and this then enables the antenna circuit to transmit at the various frequencies.

Conveniently the apparatus includes an alternating current power supply, and said set of said windings is connectable to the power supply via a return path. Thus the energy that is removed from the coil is returned to the power supply via the return path. The antenna circuit can include a further capacitor arranged in parallel with said power supply, so that the return path is connectable to said further capacitor. Preferably the return path includes a current controlling device such as a diode.

Known methods of reducing the Q factor of tuned circuits include introducing a load resistor into the antenna circuit; the arrangements of the present invention are preferable to such known methods since energy is not lost, but is fed back to the power supply.

Advantageously the coil is arranged in series with a capacitor, so that the antenna circuit behaves as a tuned circuit with a reduced Q factor.

In alternative embodiments the variable frequency transmission is alternatively provided by tapped transformer arrangements and/or switched capacitor arrangements.

The location monitoring apparatus further includes a variable frequency receiver operable to selectively receive signals at the plurality of different frequencies. More specifically, the location monitoring apparatus comprises a low frequency radio receiver comprising: at least one coil; tunable receiver circuitry arranged in operative association with the coil and being arranged to modify the frequency at which signals are received by the radio frequency receiver; signal processing means arranged to amplify and filter signals received by the radio frequency receiver; and frequency sequence identifying means arranged to identify, within a time period, a sequence of frequencies in the amplified and filtered signals.

The frequency sequence identifying means may, for example, comprise software arranged to evaluate the correlation between signals that are amplified and filtered within the time period.

Preferably the radio receiver includes three coils and a processing system arranged to operate in a first operating condition wherein, for each frequency in the sequence, each of the coils is selected, the tunable receiver circuitry is arranged to cooperate with a selected coil, and the signal processing means is arranged to amplify and filter signals received from the selected coil. The processing system can then evaluate a signal strength associated with signals received from each of the coils, which are combined to evaluate a range between the transmitter and receiver.

Further features and advantages of the various aspects of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a schematic diagram showing a situation in which location monitoring apparatus comprising a transmitter and a receiver according to the invention can be used;

Figure 2 is a schematic diagram showing components of the transmitter of Figure 1;

Figure 3 is a circuit diagram showing, in more detail, the components of the transmitter of Figure 1 according to a first embodiment;

Figure 4 is a circuit diagram showing further details of the transmitter of Figure 1 according to the first embodiment;

Figure 5 is a schematic circuit diagram showing a conventional lossy antenna circuit;

Figure 6 is a schematic circuit diagram showing the components of the transmitter of Figure 1 according to a second embodiment;

Figure 7 is a schematic circuit diagram showing the components of the transmitter of Figure 1 according to a third embodiment;

Figure 8 is a schematic diagram showing components of the receiver of Figure 1; and

Figure 9 is a flow diagram showing steps performed by the receiver of Figure 1 when identifying the range between the child and guardian shown in Figure 1.

Detailed Description of the Invention

Embodiments of location monitoring apparatus according to the invention will now be described for an example scenario whereby the location of a child is being monitored by a guardian. Referring to Figure 1, the child 1 and guardian 3 are located in a crowded area comprising obstacles, several doorways and passageways (shown collectively as part 5 in Figure 1). The child 1 is equipped with a radio frequency (RF) transmitter 11 and the guardian is holding a radio frequency (RF) receiver 13. The components and operation of the RF transmitter and receiver 11, 13 will be described in detail below, but in overview, the RF transmitter 11 transmits low frequency signals at a plurality of different frequencies, according to a predetermined frequency sequence, either constantly or in response to an external input. The signals so transmitted are received by the RF receiver 13, which identifies the frequency sequence and the amplitudes of the received signals, and from the identified amplitude, determines the range of the RF transmitter 11 and thence the relative location of the child 1.

As stated above, embodiments of the invention operate in the low frequency RF range, that is to say less than 1 MHz, preferably less than 500kHz, more preferably between 125kHz and 350kHz and most preferably between 240kHz and 315 kHz. As is known in the art, the advantage of operating in the low frequency RF range is that, rather than being reflected by obstacles and the like, the radio waves propagate through the obstructions. This means that, whereas high RF signals arriving at the receiver 13 are likely to have arrived via several paths (commonly referred to as multi-path problems), the low radio frequency signals received by the RF receiver 13 are far more likely to have traveled directly from the RF transmitter 11. Thus multi-path problems that are

experienced at high frequencies are significantly reduced.

As is also well known, low frequency devices operate in the "near field" and are generally magnetic rather than electric. In the near field, Maxwell's equations indicate that signal strength is proportional to the inverse cube of distance from the transmitter, which bounds the effective area of operation. Since signal strength is proportional to the inverse cube of distance from the transmitter, a small change in distance yields a large change in signal strength, which means that range can be identified far more accurately than is possible using higher frequency devices. In some circumstances the RF receiver 13 can identify the location of the RF transmitter 11 with an accuracy of ±10 mm.

In this example scenario, where a guardian 3 is tracking the location of a child 1 in a crowded area (e.g. a shopping precinct), there is likely to be a significant amount of background noise, which is transmitted from electronic equipment such as monitors, terminals and the like, and is in the low frequency range. Thus although low frequency signals take a more direct route between transmitter and receiver than that which would taken by high frequency signals, a receiver operating at low frequencies is likely to receive a farrago of background noise in addition to any signals emanating from a transmitter. This makes it difficult to know whether there is any data in the received signals. A solution to this problem, as presented in embodiments of the invention, is to transmit data signals at a plurality of low frequencies, in accordance with a frequency hopping pattern. The RF receiver 13 is then configured to identify the frequency hopping pattern and to lock into the identified pattern. Since the frequency hopping pattern, and thus the frequencies at which information is contained, has been identified, the signals that are received by the RF receiver 13 inherently contain signals transmitted by the RF transmitter 11. The receiver 13 is thus arranged to process signals at these identified frequencies.

Aspects of the RF receiver 13 will be described in detail later, but firstly aspects of the RF transmitter 11 will be described, with reference to Figure 2, which is a schematic of the components of the RF transmitter 11. The transmitter 11 comprises a variable frequency generator 15, a driver circuit 17 and a field generation coil 19, the latter of which acts as an antenna for the RF

transmitter 11. The variable frequency generator 15 can be provided by a direct digital synthesizer (DDS), which is a commercial off the shelf (COTS) programmable device configured to output a specified waveform (e.g. sine, square or triangular wave) at specified frequencies. The driver circuit 17 is arranged to create an alternating current of sufficient magnitude that a sufficiently high magnetic field is produced and transmitted via the coil 19.

Components of the driver circuit 17 will now be described with reference to Figure 3. In a first embodiment, the driver circuit 17, hereinafter referred to as an antenna circuit, comprises a capacitor 31, a coil 33 comprising a plurality of windings, and tapping means 35 for connection to the windings (point of connection shown in Figure 3 as tapping point 301). The capacitor 31 and coil 33 are arranged in series, and receive current from a battery 37 via switching devices 39 (it should be noted that in this embodiment coil 19 shown in Figure 2 is the coil 33 shown forming part of the antenna circuit 17). The switching devices 39 transform direct current (dc) into alternating current (ac) having a frequency is determined by the operating frequency of the DDS. Referring to Figure 4, the battery 37 can be a 3 Volt battery configured in parallel with a power rail decoupling capacitor 38, which decouples the battery 37 from the antenna circuit 17.

Conventional antenna circuits comprise a coil and a capacitor, have a very narrow band response centered around a resonant frequency (f_0) (f_0 being dependent on the reactance of the capacitor (X_C) and reactance of the inductor (X_L)), and only work within the extents of this narrow frequency band; such circuits are said to be tuned and frequency selective. One way of describing the extents of the frequencies over which the circuit responds is via a bandwidth (δf), which defines the range of frequencies within which the power output by the transmitter has halved, relative to the power output at the resonant frequency (known as the -3db bandwidth).

This property is exploited in filters as well as in tuned circuits, where the goal is to remove all signals save those within the narrow band. As is well known in the art, for series circuits operating at the resonant frequency f_0, impedance (Z) at resonance is purely resistive – this resistance is in fact what

limits the magnitude of the response at resonance (Z = $\sqrt{R^2 + (X_L - X_C)^2}$ (1) and at resonance $X_L = X_C$, $I_L = V/Z$ so that if the resistance were zero then the current flowing through the coil, and thus the response, would be infinite). The -3db bandwidth of the response is also related to resistance – for antenna circuits having higher resistance, the magnitude of the response at resonance is reduced, but the bandwidth is increased, which means that the operating band of the antenna circuit is increased.

A parameter known as Q, defined as $Q = \frac{X_L}{R}$ (2), is used to describe the dependence of bandwidth and selectivity on loss associated with the antenna circuit (associated with reactance and resistance of the coil), and the -3db bandwidth relative to the peak (at resonance), δf, of the antenna circuit is given by $\delta f = \frac{f_0}{Q}$ (3). From equation 3 it can be seen that the higher the Q factor (i.e. the lower the loss), the more selective and the narrower the bandwidth of the antenna circuit, whilst the lower the Q factor (i.e. the higher the loss) the less selective and the wider the bandwidth of the antenna circuit. It will thus be appreciated that one way of increasing the bandwidth and reducing the selectivity of the antenna circuit is by increasing the resistance thereof. However, whilst increasing the resistance of the antenna circuit by placing a resistive load in the circuit increases the bandwidth, it does so at a cost, since resistive loads consume energy for battery powered transmitters, such a loss is unacceptable.

In a first embodiment of the invention the resistance of the coil is instead increased by the inclusion of the tapping means 35, which is connected to one of the windings of the coil and provides a return path 41 back to the power supply. Preferably a diode 43, or some other type of current direction controlling device (e.g. a transistor appropriately configured), is located in the return path 41. Thus in this embodiment, energy removed from the coil 33 is returned to the power rail capacitor 38 rather than (as is the case with use of a resistive load) being dissipated as heat.

When a coil 33 is tapped, as shown in Figures 3 and 4, it effectively becomes a voltage divider comprising 2 coils, L1 and L2, each of which has a number of turns N_1, N_2 and $N_1/N_2 = n$. The power rail capacitor 38 is charged with a voltage of V_s, and, since the return path 41 is connected thereto, the peak-to-peak voltage in the return path 41 (marked as V_A) for an input voltage V_s, is $2V_s$, which means that, by applying basic transformer theory ($V_AN_1 = V_BN_2$ and $N_1/N_2 = n$) the voltage in the tuned circuit (marked as V_B) is:

$$V_B = 2V_sn. \qquad (4)$$

This means that the multiplication of voltage in the tuned circuit (i.e. between the capacitor 31 and the coil 33) is $V_B/V_{power\ supply} = 2V_sn/V_s = 2n$.

The Q factor of this arrangement can be identified by evaluating a conventional lossy antenna circuit that includes a resistive load; such an arrangement is shown in Figure 5, with the load resistor (R) being indicated as part 501. At resonance, the sinusoidal current, I, flowing through all components $I = V_s/R$ (peak-to-peak). Applying Ohms Law to individual reactance values leads to $V_B = I.X_L = 2.\pi.f_o.L.V_s/R$, where f_o is the frequency of the sinusoidal current. Since $Q = 2.\pi.f_o.L/R$,

$$V_B = V_s.Q \qquad (5)$$

Since the circuits shown in Figures 3 and 5 are equivalent (in that, in both cases, the resistance of the antenna circuit has been increased either indirectly or directly), the expressions of V_B are equivalent. Equating equation (1) with equation (2):

$$Q = 2n$$

So that the equivalent Q factor of the circuit shown in Figure 3 is double the turns ratio (n) between L1 and L2. Inserting this value of Q into equation (3), the bandwidth is now given by $\delta f = \dfrac{1}{4\pi.n.\sqrt{LC}}$ (6).

Turning back to Figure 4, it will be appreciated from the foregoing that an increase in bandwidth is accompanied by a corresponding decrease in circulating current I_c in the antenna circuit 17, and thus a decrease in magnetic field generated by the coil 33. As a result the signal strength transmitted by the transmitter can be expected to be lower than is the case for tuned circuits having

a high Q factor. One way of increasing the signal strength is to increase the amount of drive current I_d fed into the antenna circuit 17, since this will, in turn, increase the magnitude of the circulating current I_c. The drive current I_d output by the switching devices 39 is dependent, at least in part, on the Q factor of the antenna circuit, which means that a decrease in Q factor causes the switching devices 39 to draw more current from the power supply (here battery 37 in conjunction with power rail decoupling capacitor 38). This increase in drive current I_d raises the magnitude of the circulating current I_c such that a sufficiently high magnetic field, and signal strength, is generated by the coil 33.

It will be appreciated that the feature of returning energy from the coil 33 to the power rail decoupling capacitor 38 is particularly beneficial since, in the absence thereof, the battery would be drained in a shorter period of time than would be the case for a tuned circuit having a high Q factor and narrow bandwidth.

Alternative embodiments are shown in Figures 6 and 7; Figure 6 shows a transformer comprising a first coil 611 and a second coil 63, wherein the second coil is connected to the tapping means 35 and is tapped at tapping point 601, and Figure 7 shows a plurality of switched capacitors, each of which is controllable via switching means 711a, 711b, 711c. This latter embodiment is, however, rather different in operation to those shown in Figures 3, 4, 5 and 6, since switching capacitors changes the value of the capacitance of the antenna circuit, thereby modifying the value of resonant frequency f_o, rather than modifying the bandwidth around the resonant frequency:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad (7)$$

Thus for the switched capacitor embodiment shown in Figure 7, the antenna circuit 17 is frequency selective and characterized by a narrow frequency band that is centered around a movable resonant frequency value. A combination of switched capacitors and tapped coils is also possible.

The foregoing embodiments are concerned with antenna circuits wherein the components are arranged in series; the skilled person will appreciate that parallel tuned circuits can similarly be modified so as to transmit a plurality of

different frequency signals. Since the reactance of the coil and the capacitor making up the antenna circuit 17 are combined to create very low impedance in series circuits, and in parallel circuits they are combined to create very high impedance, the selection of circuit type (parallel or series) will depend on operating requirements.

It will also be appreciated that, although the tapped coil embodiments have been presented in the context of location monitoring apparatus, the antenna circuits presented in Figures 3, 4 and 6 are novel in their own right, and are not limited to low frequency operation.

Turning now to Figure 8, aspects of the RF receiver 13 will now be presented. As described above, the function of the receiver 13 is to identify and extract, from the medley of signals received at the receiver 13, those signals transmitted by the RF transmitter 11, and to measure the amplitude of the extracted signals in order to identify the distance between the receiver 13 and the transmitter 11. The receiver 13 includes three coils 81, 83, 85, each mounted orthogonally with respect to one another to receive signals; preferably each of the coils 81, 83, 85 is ferrite loaded, so as to reduce their physical size. The receiver 13 comprises receiver circuitry that is based on the well known superheterodyne architecture and includes: an RF amplifier 801, which has a tuned circuit adapted to select RF signals falling within a specified range and an amplifier adapted to amplify the selected signals; a frequency mixer 803 for mixing the amplified signals with signals generated by a local oscillator 805 so as to output signals of an intermediate frequency (IF); an IF amplifier 807 for amplifying and filtering the IF signals; a rectifier 809; an A-to-D converter 811; and a processing system 813. Components 801, 803, 807, 809, 811 make up the receiver circuitry. The IF is preferably 10 kHz, which means that the frequency of the local oscillator 803 is set 10 kHz lower than the frequency of data signals received by the RF amplifier 801.

In addition to processing of signals that have passed through the receiver circuitry, the processing system 813 is arranged to modify the frequency of operation of the local oscillator 805 and to select between the three coils 81, 83, 85. The function of parts 801, 803, 807 and 809 is conventional and will not be

described in any further detail (for further details of the superheterodyne receiver architecture the reader should refer to Chapter 5 of "Basic Radio: principles and technology" by Ian Poole, ISBN 0750626321). However, the functionality of the processing system 813, and of aspects of the local oscillator 805, are specific to the frequency hopping aspects of the data signals transmitted by the transmitter 11, and will be now be described in more detail.

As described above, the RF transmitter 11 transmits signals at a plurality of different frequencies in accordance with a frequency hopping pattern in order to combat the effects of ambient sources of interference. As a result, the RF receiver 13 has to be capable of measuring signals at any of these frequencies, and of identifying and locking onto the transmitting frequency hopping pattern. In one arrangement the local oscillator 805 is derived from a DDS module, which is operable to receive instructions from the processing system 813 and modify its operating frequency in accordance therewith. Thus the local oscillator 805 is essentially a variable frequency local oscillator (or can be thought of as a plurality of different local oscillators). Selection of the frequency of the DDS is dependent on the frequency hopping pattern utilized by the transmitter 11, so that the processing system 813 firstly has to identify the pattern and then program the DDS accordingly. The processing system 813 is accordingly configured, either in software or hardware, with means for identifying this pattern, and the functionality associated therewith will now be described with reference to Figure 9, which is a flow diagram showing steps involved in this identification.

At step 901, the processing system 813 connects to the first coil 81 so that the receiver circuitry is only processing signals received by the first coil 81. At step 903, the processing system 813 modifies the frequency of operation of the local oscillator 805 (which is coupled to the RF amplifier 801 such that the operating range of the tuned circuit therein is similarly modified), scanning across a range of frequencies. The signals received at each of the scanned frequencies are processed by the receiver circuitry and processed by the processor 813. The scanning step is repeated several times over a predetermined time period and patterns in the received signals are identified (step 905) by

means of, e.g. evaluating the correlation between successively received signals. This can be repeated for the other two coils 83, 85, but for the purposes of identifying the hopping pattern, only one of the coils needs to be utilised.

Once the frequency hopping pattern has been identified, the processing system 813 can program the frequency of operation of the local oscillator 805 (and in turn of the RF amplifier 801) to lock into the hopping pattern. Accordingly, at step 907, the processing system 813 sets the frequency of the local oscillator 805 to one of the frequencies in the hopping pattern and then connects (steps 909a, 909b, 909c), in turn, to the first, second, third coils 81, 83, 85. For each coil, the processing system 813 stores signals that are received and processed by the receiver circuitry. Having received signals from each coil, the processing system 813 switches off the coils and measures (step 909d) a reference signal (the reference signal being used to compensate for temperature-dependent gain variations of the receiver circuitry). All four measurement steps (909a – 909d) have to be performed before the transmitting frequency changes (the time period associated with the frequency hopping pattern having been established by the processing system 813 at step 905).

At step 911 the stored signals are processed in order to identify their respective amplitudes (amplitude is derived from the voltage levels associated with the received signals), and the amplitudes from each coil are then adjusted for gain variations (step 913, using the reference signal evaluated at step 909d) and the resultant signals a, b and c are processed (step 915) to determine the magnitude A of the resultant vector:

$$A = (a^2 + b^2 + c^2)^{1/2} \qquad (8)$$

The range R can then be calculated from the magnitude A by look-up of a closest match in a mapping table and/or by using an appropriate mapping function. The values in the mapping table and/or the form of the mapping function can be obtained by a calibration process during a design stage.

The signals from the coils may also be used to identify a bearing between the receiver 11 and transmitter 13. Each respective signal a, b, c, when processed in combination with the magnitude A, will provide a value indicating an angle with respect to a respective one of the x, y, and z axes as defined by the

geometry of the receiver coils. The angles can be calculated by look-up of a closest match in a mapping table and/or by using an appropriate mapping function. The mapping table values and/or the mapping function can be obtained by a calibration process during a design stage.

A bearing which is calculated from one reading using a single receiver may include at least one ambiguity. However, such ambiguity may be resolved by combining the range and bearing values from one receiver with the range and bearing values from a second receiver in a different location.

It should be noted that, if the transmitted signal has a polarization which is in concordance with the polarization of the coil, the range could be identified using one coil only. Since this will not, however, always be the case, it is preferable to use at least two, and more preferably three, coils to identify the range. Furthermore, the use of three coils also provides information on the relative bearing of the transmitter and receiver as described above.

It will be appreciated that operation of the RF receiver 13 is completely independent of the configuration of the RF transmitter 11, meaning that the means by which a frequency hopping pattern is established and signals corresponding to the frequencies are transmitted has no bearing on the operation of the receiver 13.

Whilst in the foregoing embodiments the receiver architecture is described as being that of a superheterodyne receiver, it could alternatively be direct conversion or regenerative; in particular, if the receiver were implemented as an integrated circuit, the implementation would most likely use direct conversion.

Whilst in the foregoing embodiments the processing system 813 and receiver circuitry 801, 803, 805, 807, 809, 811 are arranged to process signals received from all 3 coils, the receiver 13 could alternatively comprise 3 separate sets of receiver circuitry (one for each coil). This would allow signals received by each of the coils to be processed in parallel rather than sequentially and would have advantages in terms of reduced measurement time at the expense of increased complexity.

Whilst in the foregoing embodiments the RF receiver 13 comprises 3

coils, the receiver 13 could alternatively comprise three independent receiver units, each having a single coil and receiver circuitry, the output of which is input to a centralized processing system 813 and processed in the manner described above.

Whilst the above embodiment is presented in the context of tracking the location of a child, by a guardian, many other short range applications of the location monitoring apparatus are possible. For example, location monitoring apparatus according to the invention could be used in hazardous areas such as construction sites, sites attended by the emergency services (e.g. a building on fire) and on boats, where visibility of personnel is poor; in hospitals and health care facilities; in gaming scenarios; and for locating objects (e.g. objects mislaid around the house or office). Other applications are envisaged.

It will be understood that the present disclosure is for the purpose of illustration only and the invention extends to modifications, variations and improvements thereto, and that any elements of the different embodiments may be combined to form further embodiments of the invention.

The application of which this description and claims form part may be used as a basis for priority in respect of any subsequent application. The claims of such subsequent application may be directed to any feature or combination of features described therein. They may take the form of product, method or use claims and may include, by way of example and without limitation, one or more of the appended claims.

Claims

1. Location monitoring apparatus comprising a variable frequency transmitter operable to selectively transmit signals at a plurality of different frequencies, each of which is less than 1 MHz.

2. Location monitoring apparatus according to claim 1, comprising an antenna circuit having a variable impedance and a frequency bandwidth associated therewith, the frequency bandwidth defining a frequency band within which the radio frequency transmitter is operable to transmit signals, wherein the antenna circuit is operable to modify the impedance so as to modify said frequency bandwidth, and to transmit a radio frequency signal having a frequency within said modified frequency bandwidth.

3. Location monitoring apparatus according to claim 2, wherein the antenna circuit includes a coil comprising a plurality of windings and tapping means for connection to said windings so as to vary the frequency bandwidth of the antenna circuit.

4. A radio frequency transmitter according to claim 3, wherein the tapping means is arranged to connect to a set of the plurality of windings.

5. Location monitoring apparatus according to claim 3 or claim 4, wherein the antenna circuit has a capacitance arranged in series with said coil.

6. Location monitoring apparatus according to claim 2, wherein the antenna circuit comprises:

a transformer comprising a first coil having a first plurality of windings and a second coil having a second plurality of windings; and

tapping means for connection to said second plurality of windings so as to vary the frequency bandwidth of the antenna circuit.

7. A radio frequency transmitter according to claim 6, wherein the tapping means is arranged to connect to a set of the second plurality of windings.

8. Location monitoring apparatus according to claim 7, wherein the antenna circuit has a capacitance arranged in series with the transformer.

9. Location monitoring apparatus according to any one of claim 4 to claim 8, including an alternating current power supply, wherein said set of said windings is connectable to the power supply via a return path.

10. Location monitoring apparatus according to claim 9, wherein the return path includes a diode.

11. Location monitoring apparatus according to claim 9 or claim 10, wherein the alternating current power supply comprises a battery and switching means arranged, in response to receipt of current from the battery, to output an alternating current.

12. Location monitoring apparatus according to claim 11, including variable frequency generation means arranged in operative association with said switching means, wherein the frequency of the alternating current output from said switching means is variable in accordance with input received from the variable frequency generation means.

13. Location monitoring apparatus according to any one of claim 9 to claim 12, including a further capacitor arranged in parallel with said power supply, wherein the return path is connectable to said further capacitor so as to return current from said set of windings to the further capacitor.

14. Location monitoring apparatus according to claim 2, wherein the antenna circuit has a variable reactance.

15. Location monitoring apparatus according to claim 14, wherein the antenna circuit comprises a coil, a plurality of switchable capacitors and means for selectively switching between said capacitors so as to modify the reactance of the antenna circuit.

16. Location monitoring apparatus according to claim 15, wherein the coil is arranged in parallel with at least some of said plurality of switchable capacitors.

17. Location monitoring apparatus according to any one of the preceding claims, including a radio frequency receiver comprising:

at least one coil;

tunable receiver circuitry arranged in operative association with the coil and being arranged to modify the frequency at which signals are received by the radio frequency receiver;

signal processing means arranged to amplify and filter signals received by the radio frequency receiver; and

frequency sequence identifying means arranged to identify, within a time period, a sequence of frequencies in the amplified and filtered signals.

18. Location monitoring apparatus according to claim 17, wherein the frequency sequence identifying means is arranged to correlate the processed signals with one another in order to identify said sequence of frequencies.

19. Location monitoring apparatus according to claim 17 or claim 18, including three coils and a processing system arranged to operate in a first operating condition wherein, for each frequency in the sequence, each of the coils is selected, the tunable receiver circuitry is arranged to cooperate with a selected coil, and the signal processing means is arranged to amplify and filter signals received from the selected coil.

20. Location monitoring apparatus according to claim 19, wherein the processing system is arranged to receive signals amplified and filtered by the signal processing means and to identify signal strength associated therewith.

21. Location monitoring apparatus according to claim 20, including evaluating a range between the variable frequency transmitter and the radio frequency receiver on the basis of the signal strengths associated with the signals received by the three coils.

22. A radio frequency transmitter comprising an antenna circuit having a frequency bandwidth associated therewith, wherein the antenna circuit comprises a coil having a plurality of windings, and is arranged to transmit a radio frequency signal,

characterized by tapping means for connection to said windings, the tapping means being in operative association with the coil so as to increase the frequency bandwidth of the antenna circuit.

23. A radio frequency transmitter according to claim 22, wherein the tapping means is arranged to connect to a set of the plurality of windings.

24. A radio frequency transmitter according to claim 23, including an alternating current power supply, wherein said set of windings is connectable to the power supply via a return path.

25. A radio frequency transmitter according to any one of claim 22 to claim 24, wherein the return path includes a diode.

26. A radio frequency transmitter according to claim 25, including a capacitor arranged in parallel with said power supply, wherein the return path is connectable to said capacitor so as to return current from said selected set of windings to the capacitor.

27. A radio frequency transmitter according to any one of claim 24 to claim 26, wherein the alternating current power supply comprises a battery and switching means arranged, in response to receipt of current from the battery, to output an alternating current.

28. A radio frequency transmitter according to claim 27, including variable frequency generation means arranged in operative association with said switching means, wherein the frequency of the alternating current output from said switching means is variable in accordance with input received from the variable frequency generation means.

29. A radio frequency transmitter according to any one of claim 23 to claim 28, wherein the transmitted radio frequency signal has a frequency less than 1 MHz.

30. A radio frequency transmitter comprising an antenna circuit, wherein the antenna circuit comprises a capacitance (C), and a coil comprising a plurality of windings having an inductance (L), the antenna circuit having a frequency bandwidth (δf) associated therewith and including tapping means for connection to the coil so as to create a first set of windings and a second set of windings, each set of windings having a number of turns, wherein the number of turns of the first set is related to the number of turns of the second set by a turns ratio (n), and the frequency bandwidth of the antenna circuit is at least

$$\delta f = \frac{1}{4\pi . n . \sqrt{LC}}.$$

31. A radio frequency receiver comprising:

at least one antenna coil;

tunable receiver circuitry arranged in operative association with the antenna coil and being arranged to modify the frequency at which signals are received by the radio frequency receiver;

signal processing means arranged to amplify and filter signals received by

the radio frequency receiver; and

frequency sequence identifying means arranged to identify, within a time period, a sequence of frequencies in the amplified and filtered signals,

wherein the radio frequency receiver is operable to receive signals having a frequency less than 1 MHz.

32. A radio frequency receiver according to claim 31, wherein the frequency sequence identifying means is arranged to correlate the processed signals with one another in order to identify said sequence of frequencies.

33. A radio frequency receiver according to claim 31 or claim 32, including three antenna coils and a processing system arranged to operate in a first operating condition wherein, for each frequency in the sequence, each of the antenna coils is selected, the tunable receiver circuitry is arranged to cooperate with a selected antenna coil, and the signal processing means is arranged to amplify and filter signals received from the selected antenna coil.

34. A radio frequency receiver according to claim 33, wherein the processing system is arranged to receive signals amplified and filtered by the signal processing means and to evaluate signal strength associated therewith.

35. A radio frequency receiver according to claim 34, including evaluating a range between the variable frequency transmitter and the radio frequency receiver on the basis of the signal strengths associated with the signals received by the three antenna coils.

36. A radio frequency receiver according to any one of claim 31 to 35, wherein, for each frequency in the sequence, the processing system is arranged to operate in a second operating condition wherein none of the antenna coils is selected and the signal processing means is arranged to amplify and filter signals corresponding to the second operating condition.

37. A radio frequency receiver according to claim 36, wherein the processing system is arranged to use the filtered and amplified signals corresponding to the second operating condition to modify the signal strengths corresponding to the first operating condition.

38. A radio frequency receiver for use in a location monitoring system, the radio frequency receiver comprising:

three antenna coils, each antenna coil being operable to receive radio frequency signals emitted by a radio frequency transmitter;

signal processing means arranged to amplify and filter signals received by the selected antenna coil; and

selecting means arranged to select each of the three antenna coils in accordance with a specified selection procedure, and to pass signals from the selected antenna coil to the signal processing means.

39. A radio frequency receiver according to claim 38, including a processor arranged to process filtered signals corresponding to the three antenna coils in accordance with a predetermined location determining algorithm so as to identify the location of signals emanating from the radio frequency transmitter.

40. A radio frequency receiver according to claim 39, wherein the processor is integral with the radio frequency receiver.

41. A radio frequency receiver according to claim 39, wherein the processor is separate from the radio frequency receiver.

Abstract

Location monitoring apparatus

Embodiments of the invention are concerned with location monitoring apparatus and are concerned particularly with radio frequency location monitoring apparatus that operate in the low radio frequency range. Embodiments of the present invention also relate to radio frequency transmitter and radio frequency receiver designs generally.

In one aspect of the invention, embodiments describe location monitoring apparatus comprising a variable frequency transmitter operable to selectively transmit signals at a plurality of different frequencies, each of which is less than 1 MHz.

Also in this aspect of the invention, embodiments operate in the low frequency range, which means firstly that multi-path problems associated with high frequency equipment (such as reflections from objects located between the path of the transmitter and receiver) are significantly reduced, and secondly that distance can be identified extremely accurately. In addition, having a variable frequency transmitter means that ambient noise can be filtered out, since noise is typically constant over time and concentrated at particular frequencies.

Figure 3